Deformation of a Sandbar in Response to Changes in Effective Stress Along the Colorado River in the Grand Canyon, Arizona

By M.C. Carpenter

Discharge from Glen Canyon Dam on the Colorado River can fluctuate from about 85 to 800 m^3/s on a daily basis. Corresponding river-stage fluctuations on downstream beaches can exceed 3.4 m. Rill erosion, slumping, and fissuring on seepage faces of many sandbars observed at low river stage are a response to ground-water flow caused by residual hydraulic-head gradients in the sandbars, which is the result of river-stage fluctuation.

From April 1991 to March 1993, a sandbar was instrumented with sensors for continual monitoring of river stage, pore pressure, temperature, and biaxial tilt to determine relations among ground-water flow, changes in effective stress, seepage stresses, and sandbar deformation. Five clusters of deep, intermediate, and shallow pairs of pore-pressure and temperature sensors were installed in a vertical plane orthogonal to the river's edge. The clusters were spaced a few meters apart in the sandbar face above, within, and below the zone of fluctuating river stage to determine the vertical component of ground-water flow in the deforming sandbar face. The clusters were spaced more than 10 m apart in the middle and back of the sandbar. Seven tilt sensors were installed parallel with and orthogonal to the river's edge in the deforming sandbar face.

The sandbar consisted of homogeneous fine to medium sand overlying medium sand at a depth of 6 m. The back boundary was talus with a narrow, deep, return channel underlain by a thin clayey silty sand. The zone of fluctuating river stage was a steeply sloping face that exhibited rill erosion, slumping, and fissuring.

A sequence of tilts occurred from July 7, 1991, through July 17, 1991. The tilts were at least five times greater orthogonal to the river than parallel to the river. The sign convention for tilts ortho- gonal to the river is positive for tilts upward toward the river and negative for tilts downward toward the river. On July 7, a tilt of 5.5∞° occurred orthogonal to the river. On July 12, a tilt of -0.5°∞ occurred; and on July 17, an additional tilt of -3.3°∞ occurred. These major occurrences were followed by continued negative tilt orthogonal to the river from July 18 to July 26, punctuated with daily spikes of about -0.4°π. All sudden tilts occurred on downward limbs of the daily hydrographs when the effective stress (intergranular stress) in the sandbar face was increasing. The hypothesis sug- gested is a slump-creep sequence: (1) outward- flowing ground water caused oversteepening of the lower part of the slope in the zone of fluctuating river stage by rilling; (2) slumping (rotational failure) of the metastable slope was triggered by increased effective stress; and (3) leveling of the slightly uplifted mound on the toe slope of the slump block occurred by downslope creep.